

Breakout report for the NASA Applied Sciences Program

Future Satellite Missions in Support of NASA Water Resources Applications Input to the NRC Decadal Survey

The main aim of this discussion was to solicit information from the participants of the NASA Water Resources Applications program participants at their annual meeting for input the forthcoming National Research Council (NRC) Decadal Survey.

The participants were given the option to choose one of the four groups (a) Droughts (b) Floods (c) Water Resources Quantity and Quality and (d) Agriculture. Each group was presented the same set of five questions listed below and their responses were recorded in a similar format.

- (1) What are the applied science questions and priority topics of societal relevance?
- (2) What observations are needed to address these priority topics, and what are the observation requirements (spectral characteristics, spatial resolution, observation frequency, duration)?
- (3) What analysis frameworks would be applied to the observations to address these science questions and priority topics (algorithms, models, data assimilation frameworks)?
- (4) To ensure that the observations can be applied to address the priority topics, what are the requirements for mission ground data segments and data systems?
- (5) What are recent examples of successful applications of satellite observations to address water resource management challenges? Where possible, please quantify the impact of use of satellite observations on the management challenge or decision making process.

Science Questions

Agriculture

The overarching theme for agriculture is detection and mitigation of threats to food security. Additionally, the scientific focus of this thematic area is improvement of crop yields and water productivity to meet increased global demand for food, while also protecting ecosystem services and sustaining water supplies. Priority topics of societal relevance include monitoring water use, water resource quantity and quality, monitoring crop water and nutrient stresses, supporting decision making associated with allocation of water resources to competing uses, and increasing resiliency to climate stresses. Key applied science questions identified by participants include:

- (i) What are the feedbacks from agriculture management practices (e.g., withdrawals, drainage, tillage practices) to regional hydrology?
- (ii) What factors determine resiliency of agriculture to climate extremes?
- (iii) What are the primary drivers of variability of agricultural yields?

Floods

Flooding is one of the most costly and frequent natural disasters faced by the United States and the world. The various losses in a flood include (a) Loss of life (b) Loss of property (c) Loss of opportunity (d) Cost of remediation (diversion of flows) (e) Protection costs (levees). Priority topics and science questions identified by participants for this theme include:

- (i) How can we improve the precision of information on flow, stage, timing of the peak and length of the recession limb for streamflow hydrographs?
- (ii) How can we reconcile the cost of a false warning versus the cost of no warning?
- (iii) Quantification of uncertainty and communication of information is very important (a) Inundation mapping (b) Risk = probability of flooding * cost of damages. What are the best methods to quantify this uncertainty?
- (iv) What spatial scales and temporal repeat are needed to characterize the post flood damages?

Droughts

Lack of precipitation, or imbalances between precipitation and evapotranspiration and/or consumptive use results in meteorological and agricultural droughts. Monitoring and forecasting the onset of droughts and the recovery from droughts are issues of societal relevance. Key applied science questions identified for this them include:

- (i) How do droughts affect water and food security from local to regional to continental scales?
- (ii) How can satellite observations be applied to map key indicators of drought onset and severity?
- (iii) How can improve prediction of drought onset and termination to provide adequate lead-time for planning for drought mitigation?

Water Quality

Poor water quality can result in impacts on human health, environmental degradation, and significant economic costs in both private and public sector. The lack of adequate treatment for drinking water and sanitation has cost millions of lives, particularly in the developing country context. In an industrial setting, water quality is an important concern for both input and output streams. Examples of water quality issues include harmful and nuisance algal blooms, nutrient loading, pathogens, sediment, endocrine disruptors, oil, dissolved organic matter, disinfection byproducts, among many others. A few applied science questions related to water quality may include:

- (i) How do we help reduce the number of people impacted by water, sanitation, and hygiene issues?
- (ii) How do we more efficiently monitor source water quality (and optimize treatment efforts) for agriculture, residential use, industry (hydropower, recreation, transportation, etc), public health, and ecosystem needs?
- (iii) How do we track output water quality and minimize discharge of pollution into the environment?
- (iv) How do we build water quality impacts monitoring into urban infrastructure planning/construction?
- (v) How can we advance our ability to monitor, predict, and respond to changes in water quality?

Observation needs and requirements

Agriculture

Variable	Δx	Temporal Repeat	Overpass time	Duration	Notes/Accuracy Requirement
Crop type	10-30 m, hyperspectral	Weekly	Least cloudy, twice per day? (consider constellation approach)	Long term	Sustained Land Imaging (SLI) + hyperspectral information
Crop phenology	10-30 m, multispectral	Weekly, near daily in critical parts of the cycle	Least cloudy, twice per day? (consider constellation approach)	Long term	Sensor fusion, also used in mapping of irrigated areas
Indicators of different types of crop stress (water nutrient, disease, heat, humidity, pest)	10-30 m, hyperspectral to distinguish different types of stress, thermal	Weekly, consistent overpass time(s) to allow computation of anomalies	Afternoon	Long term	Doesn't need to be polar orbiting, ~60N to 60S
Water use (ET and separation of E&T)	10-30 m, multispectral and thermal	Weekly	Least cloudy, twice per day? (Constellation approach)	Long term	Sustained Land Imaging (SLI)
Land surface temperature	10-30 m, thermal (or 1km ka band microwave as a proxy as alternative)	Weekly	Least cloudy, twice per day? (Constellation approach)	Long term	Also used to derive irrigated area
Soil moisture profile (Surface v root zone)	1-3 km, microwave	Daily	Early morning	Long term	SMAP follow-on
Vegetation water content	1-3km, microwave			Long term	Sensor fusion using microwave and

					thermal to derive estimates at field scale
Chlorophyll content	10-30 m, multispectral/ hyperspectral	Weekly		Long term	Crop residue mapping
Precipitation		Hourly		Long term	GPM Follow-on
Irrigated area	10-30m	Seasonal		Long term	Derived from NDVI and LST
Leaf area index	10-30 m, multispectral or Lidar	Weekly		Long term	
Water use efficiency	10-30 m	Weekly		Long term	Derived from model
Solar radiation (at the land surface)	1 km	Hourly		Long term	
Boundary Level Humidity	2-4 km	Hourly	Geostationary	Long term	Improvement over AIRS
Canopy height	30 m, accuracy +/- 30 cm	Annual			
Soil type					

Floods

Variable	Δx	Temporal Repeat	Overpass time	Duration	Notes Accuracy
Precipitation	<1km	Hourly	X	Unlimited	<10%
Topography	10m	3-5 years	X	X	10cm
Soil Moisture	1km	Daily	6am/pm	Unlimited	<10%
Land use	10m	Weekly	X	Unlimited	<5%
Land cover					
Groundwater	100m	Daily	Anytime	Unlimited	5cm
Ponded Water	10m	Daily	Anytime	Unlimited	1cm vertical
Soil Properties	100m	10 years	X	X	<10%
Farming practice	10m	Seasonal	X	X	Tillage/No tillage
ET demand	1km	Hourly	X	Unlimited	<10%
Stream cross-section	1m	Seasonal	X	X	1cm
W/S profile	100m	Daily/ 4/Day Tidal	6am/pm	X	5cm
Snow cover	10m	Daily	6am/pm	X	<10%
SWE	10m	Daily	6am/pm	X	<10%
River ice cover	1m	Daily	6am/pm	X	<10%
Ice dam	1m	Daily	6am/pm	X	<10%
Ice dam breakup	1m	Hourly	6am/pm	X	<10%
Levee integrity	10m	Daily	On demand	X	<10%
Solar radiation	100m	Hourly	X	X	<10%
Cloud cover	100m	Hourly	X	X	<10%

Droughts

Variable	Δx	Temporal Repeat	Overpass time	Duration	Notes
Groundwater	25 km	Weekly	N/A	30 years	Continuity important
ET/Water Vapor	100 m	Daily	Early morning	10 years	Field scale, high repeat
Snowpack	100 m	Weekly	Daytime	Forever	
Soil Moisture (Rootzone included)	1 km (higher level product)	Daily	Morning	Forever	Continuity important
Vegetation Water Content	1 km	Daily	Morning	Continuous	
Surface water	10 m	Weekly	Daytime	Continuous	
Precipitation	1 km	Hourly	N'A	Continuous	

Water quantity and quality

Variable	Δx	Temporal Repeat	Overpass time	Duration	Notes Accuracy
Root-zone column Soil moisture	50m-1Km	Weekly			
ET	30m	Daily			
Water quality- chlorine, salinity, suspended mineral, cdom, turbidity, bacteria count, algae (HABs, ABs)	10-30m	Daily	AM		
SWE, snow albedo	10m-30m	Weekly			
Surface water volume	50m				
Surface water height					1cm over 50m
Ground Water	500m	Weekly			
Ice on/off					
Precipitation	1km	3 hourly			Phase/solid/liquid

Analysis and Model frameworks

Agriculture

Models	Data Assimilation	NASA Model data	Algorithms	Notes
Surface energy balance models	LST, NDVI, LAI	LDAS for ETo estimation	Data fusion at different spatial and temporal scales, fusion from different instruments and wavelengths	Merge thermal with ka band microwave to provide data for regions with persistent cloud cover seasonally
Crop yield models	LAI, temp, soil moisture, surface info, water and heat stress, solar radiation			Coupled with land surface models
Land surface models	Multiple remote sensing products + ancillary data on soil type, weather, etc.			
Radiative transfer modeling			Soil moisture retrieval	
ET Modeling	Land surface temperature, emissivity, incoming radiation, surface winds, local scale humidity			Need ground observations
Crop water requirements	NDVI, LAI, crop type, irrigated area, incoming radiation, surface winds, local scale humidity			

Floods

Models	Data Assimilation	NASA Model data	Algorithms	Notes
LIS CREST	NLDAS GLDAS			

Droughts

Models	Data Assimilation	NASA Model data	Algorithms	Notes
Drought Early Warning	Seasonal predictions, water supply/demand, non-natural components (irrigation, dams, etc.)	LIS, GEOS-5		
Socio- economic impacts	Socio- economic data			Non-direct/non- agricultural impacts

Water quantity and quality

****We need support for more distributed models that will ingest remote sensing data**

Models	Data Assimilation	NASA Model data	Algorithms	Notes
Distributed vs. Lumped				
VIC				
WRF				
Snow 17				
Noah, CLM,				
CLSM,				
Parameter				
LACE,				
SWAT				

**PRMS (USGS
implementing)
SPARROW,**

Harmful Algal Blooms (HAB)

Ground systems and data requirements

Agriculture

- (i) Latency < 24 hours
- (ii) Intuitive bulk download of data
- (iii) Support for cloud-based or supercomputer data processing at the DAACs to accelerate data analysis
- (iv) Data formats used by missions must be compatible with geospatial analysis software available to the community
- (v) Adequate support for analysis of mission data
- (vi) Consistent grids and metadata formats across missions (square grid cells would be a big plus)
- (vii) Delivery of higher-level products
- (viii) Support for early adopter programs

Floods

- (i) Precipitation – raingage, radar; Streamflow – stream gage (?), discharge, stage; Groundwater levels, Soil moisture, Surface temperature, ET (pan, eddy covariance)
- (ii) Ground data has to be telemetered to NOAA; quality control, analysis, distributed, data assimilation
- (iii) Network design – variable depending on topography, land cover and physical processes (governed by spatial correlation)
- (iv) Gage density for rainfall has recommendations

Drought

- (i) Global coverage but downscaled to regional-relevant products
- (ii) Open data sharing, data format/exchange standards
- (iii) Continuity, data recovery and historical as well as real-time

Water Quantity and Quality

- (i) You need ground meteorological stations in each of the principal land cover and climatic regions.
- (ii) Would need occasional ground and airborne field experiments or calibration/validation efforts that ensure
- (iii) List of ground data network requirements - Same as variables identified in question 1
- (iv) Watershed-scale planning for data field campaigns
- (v) WQ-In situ monitoring with potentially some analytical work in-lab
- (vi) Water quality / ocean color products / optical properties calibration
- (vii) Use of “intermediary” platforms such airborne/AUV/UAVs important link for ensuring utility of satellite remote sensing of water quality/ocean color
- (viii) These platforms are also rapidly deployable, which are important for responding to and characterizing water quality events (such as harmful algal blooms, oil spills or some other contamination event; storm events are another

potential driver of contamination, so being able to capture post-storms is important))

- (ix) Ideal temporal frequency is daily to weekly for water quality monitoring
- (x) Most ocean color atmospheric correction algorithms were developed over open ocean – need to test/validate for coastal and smaller inland systems – over optically complex waters

Examples of recent successes

Agriculture

Application/Location	Stakeholder	NASA Data Satellite/Model	Reference
Yield forecasting	FAS	AMSR-E, SMAP, GPM, 2 layer palmer model	Bolton, et al, 2012
Fallowed area mapping	CDWR, CDFA	Landsat, MODIS	Melton, et al, in prep
ET mapping for water rights and irrigation manage	Western states water agencies		Anderson, et al, 2012 or 2013; Allen papers
GRACE-derived drought indicators	USDM, NDMC	GRACE, NLDAS, NASA catchment land surface model	Houborg, et al, 2012
ESI agricultural drought mapping and early detection	NOAA, NDMC	Landsat, MODIS, GOES	Otkin et al., 2014; Anderson et al., 2011
Cropland data layer/ CropScape	USDA NAS	Landsat, DMC	Han et al., 2012
GEOGLAM			Whitcraft et al., 2015
Global map of irrigated areas		MODIS	Salmon, 2013 (dissertation); Thenkabail et al.

Floods

Application/Location	Stakeholder	NASA Data Satellite/Model	Reference
Flood extent Mapping/Mekong	Mekong River Commission	MODIS	AGU2014 Doyle
Global NRT flood mapping	Everyone	MODIS	Policelli, Slayback
Red River/Minnesota/ND	Emergency managers	GRACE	Rodell et al
		SMAP	Jacobs et al
		MODIS	Wood et al
		SMAP	
Flood forecasting/warning (<14 days)	Various S. Asia agencies (Bhutan, Pakistan, others)	JASON-2	SERVIR/Faisal Hossain

Droughts

Application/Location	Stakeholder	NASA Data Satellite/Model	Reference
US Drought Monitor	US	NLDAS, GRACE	
FEWS-NET	USAID, International	NDVI	Verdin
USDA-FAS	USDA	Soil moisture	Bolten

Water quantity and quality

Application/Location	Stakeholder	NASA Data Satellite/Model	Reference
ASO and MODSCAG	CDWR, Cal Cooperators, Bureau of Rec, Upper Colorado River Commission, Lower Colorado states	MODIS (for MODSCAG), ASO is an airborne LiDAR+imaging spectrometer	Painter et al
USDM			
EPA coastal Florida (lehrter)	Florida EPA	SeaWiFS	Schaeffer et al 2012, ES&T
Great Lakes HAB monitoring	Ohio and Toledo water intake managers	Airborne hyperspectral	Lekki, Liou
Red River flood forecasting			Jacobs
USDA FAS soil moisture application			
HABs bulletin	NOAA	MODIS	Stumpf et al (multiple)

References

Agriculture references

- Allen, R. G., Tasumi, M., & Trezza, R. (2007). Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Model. *Journal of irrigation and drainage engineering*, 133(4), 380-394.
- Allen, R. G., Tasumi, M., & Morse, A. (2005, February). Satellite-based evapotranspiration by METRIC and Landsat for western states water management. In *US Bureau of reclamation evapotranspiration workshop* (pp. 8-10).
- Anderson, M. C., Allen, R. G., Morse, A., & Kustas, W. P. (2012). Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources. *Remote Sensing of Environment*, 122, 50-65.
- Anderson, M. C., Kustas, W. P., Hain, C. R., Cammalleri, C., Gao, F., Yilmaz, M. T., ... & Houborg, R. (2013). Mapping surface fluxes and moisture conditions from field to global scales using ALEXI/DisALEXI. *Remote Sensing of Energy Fluxes and Soil Moisture Content*, 207-232.
- Bolten, J. D., Rodell, M., Zaitchik, B., Ozdogan, M., Anderson, M., Bergaoui, K. B., ... & McDonnell, R. A. (2012). Evaluation of the Middle East and North Africa Land Data Assimilation System.
- Bolten, J. D., & Crow, W. T. (2012). Improved prediction of quasi-global vegetation conditions using remotely-sensed surface soil moisture. *Geophysical Research Letters*, 39(19).
- Fritz, S., See, L., McCallum, I., You, L., Bun, A., Moltchanova, E., ... & Obersteiner, M. (2015). Mapping global cropland and field size. *Global Change Biology*.
- Han, W., Yang, Z., Di, L., & Mueller, R. (2012). CropScope: A Web service based application for exploring and disseminating US conterminous geospatial cropland data products for decision support. *Computers and Electronics in Agriculture*, 84, 111-123.
- Houborg, R., Rodell, M., Li, B., Reichle, R., & Zaitchik, B. F. (2012). Drought indicators based on model-assimilated Gravity Recovery and Climate Experiment (GRACE) terrestrial water storage observations. *Water Resources Research*, 48(7).
- Melton, F. S., Johnson, L. F., Lund, C. P., Pierce, L. L., Michaelis, A. R., Hiatt, S. H., ... & Nemani, R. R. (2012). Satellite irrigation management support with the terrestrial observation and prediction system: a framework for integration of satellite and surface observations to support improvements in agricultural water resource management. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, 5(6), 1709-1721.
- Salmon, J. M., Friedl, M. A., Froking, S., Wisser, D., & Douglas, E. M. (2015). Global rain-fed, irrigated, and paddy croplands: A new high resolution map derived from remote sensing, crop inventories and climate data. *International Journal of Applied Earth Observation and Geoinformation*, 38, 321-334.
- Thenkabail, P. S., Biradar, C. M., Noojipady, P., Dheeravath, V., Li, Y., Velpuri, M., ... & Dutta, R. (2009). Global irrigated area map (GIAM), derived from remote sensing, for the end of the last millennium. *International Journal of Remote Sensing*, 30(14), 3679-3733.

Whitcraft, A. K., Becker-Reshef, I., Killough, B. D., & Justice, C. O. (2015). Meeting earth observation requirements for global agricultural monitoring: An evaluation of the revisit capabilities of current and planned moderate resolution optical earth observing missions. *Remote Sensing*, 7(2), 1482-1503.

Floods

Colin Doyle, Michael Gao, Joseph Spruce, John D Bolten and Samuel Weber, Utilizing NASA Earth Observations to Enhance Flood Impact Products and Mitigation in the Lower Mekong Water Basin, at the Fall AGU Meeting, December 15-19 2014, San Francisco

Nigro, J., D. Slayback, F. Policelli and R. Brakenridge, NASA/DFO MODIS Near Real Time (NRT) Global Flood Mapping Product, Evaluation of Flood and Permanent Water Detection, October 2014,
(http://oas.gsfc.nasa.gov/floodmap/documents/NASAGlobalNRTEvaluationSummary_v4.pdf)